EFFECTS OF ROAD SURFACING AND SALTING ON ROADSIDE VEGETATION IN NEW MEXICO MOUNTAIN AREAS

JOB COMPLETION REPORT

FOR

PROJECT 16 - 361 - CA

RESEARCH WORK UNIT RM

EFFECTS OF ROAD SURFACING AND SALTING ON ROADSIDE VEGETATION IN NEW MEXICO MOUNTAIN AREAS

JAMES R. GOSZ
DEPARTMENT OF BIOLOGY
UNIVERSITY OF NEW MEXICO

DECEMBER 1974

INTRODUCTION

The increased winter use of forested areas for recreation and second homesites has resulted in road improvement activites and road salting. The use of road salt to maintain ice free roads has long been an accepted practice. Herrington (1967) lists five potential ski areas in New Mexico and sixteen in Colorado. It is expected that the roads built to service these facilities will be salted.

The specific objectives of these investigations were to:

1. quantify the effects of road paving and winter road salting on the development of stress symptoms in roadside aspen trees in the Tesuque Watersheds of the Santa Fe National Forest, and;
2. identify the site and road characteristics which significantly affect the development and severity of damage, and;
3. recommend methods and procedures for reducing objectionable levels of damage.

FIELD STUDIES

I. Establishment of Study Sites

Twelve locations were established in early June 1973 along Forest Road 101 in the Tesuque Watersheds of the Santa Fe National Forest. An additional control location (Location 13) was established along an unsalted, unmaintained special use road within the watersheds. Each location contains three study sites: an uphill site (above road cut) which is not directly affected by road salting; a site whose upper boundry is 8.0 m

below the edge of the pavement, and; a site whose upper boundry is 24.0 m below the edge of the pavement. Within each site 15 trees were selected for measurement of chloride content of the leaves.

At each location the width of the road shoulder, aspect, elevation, and the distance from road to trees (in 8 m sites only) were measured. Each tree was numbered and its DBH recorded.

II. Field Collections

Soil and vegetation samples were collected from all sites during three periods: mid June, mid August and late September. During each collection leaf samples were collected from all trees in each site (585 samples/ collection). Five soil samples were collected from each site (195 samples/ collection). Soil samples were collected from the top 25 cm of the solum.

III. Analysis and Methodology

Soil samples were routinely analysed for the following items: water content, gravel, sand, silt, clay, organic matter, and chloride content. Depth of the forest floor was measured during the collections and recorded. Water content was determined gravimetrically (Lull and Reinhart, 1955); gravel was weighed after screening the dried soil samples through a 2 mm soil screen, and; sand, silt and clay contents were determined by the Boyoucous hydrometer method. Soil organic matter was determined by the weight loss following ignition in a muffle furnace. Soil chloride was extracted in demineralized water in a 2:1 water:soil extract (Sonneveld and Van Den Ende, 1971). Chloride

content was measured with a Cl specific ion electrode.

Leaf samples were oven dried in a forced air oven at 80 °C for 48 hrs and ground in a Wiley mill to pass through a 20-mesh screen. Chloride was extracted with dilute (0.1 N) nitric acid (Cantliffe et al., 1970) and measured with a Cl specific ion electrode.

LABORATORY EXPERIMENTS

Laboratory experiments were supposed to measure the influence of Cl concentrations and water stress on the production of suckers, the rate and amount of suckering, and, determine the amount of chloride and/or moisture stress required to produce foliar damage. I am sorry to report that this portion of these investigations, to date, have not been successful. Initially root segments were collected from an aspen clone which was not subjected to road salting. In a subsequent series of experiments I found that while suckers were rapidly produced, roots did not develop and these adventitious shoots soon died. The same series of experiments were repeated in various media (nutrient solution, vermiculite and sand) as well as out-of-doors but results were always the same.

In a subsequent experiment approximately 250 small (0.3 - 0.6 m tall) aspen trees were collected from an old logged area which is not subject to road salt. The objective was to get individuals with established root systems. These trees were placed in nutrient solutions in the greenhouse, however only eight of the trees survived.

In the most recent experiment cuttings were collected from 2 to 3 m tall trees and cut in 15 cm sections. An attempt was made to root these following a variety of treatments with indolebutyric acid. Of the 500 cuttings so treated only one survived.

We are continuing to experiment with aspen rootings as well as those of related species. A major objective will be to find a procedure which allows the development of a root system. A well developed root system is required to extrapolate laboratory findings to field problems.

RESULTS

Table 1 lists the physiographic and road characteristics of the study locations. As can be seen, the variability in these factors is appreciable both within and between locations. No attempt was made to measure differences of slope, aspect or elevation within locations. This unfortunate oversite may have lead to some of the non-significant relationships encountered (see following paragraphs) and other variables which may be important were not measured at all (e.g., road width, bank and slope of road).

Stress symptoms developed only in trees on the 8 m sites. Table 2 illustrates the rate of development and the final amount of damage in these sites during these investigations. Two of the locations (3 and 9) as well as the control location (13) never developed stress symptoms in the trees we were studying.

Damage first became apparent in August while the largest amount of damage was found during the September collection. The total amount and the rate of development of this damage was exceedingly variable between locations. Differences within individual locations were also noted with groups of trees in one area of a site developing stress symptoms while other trees remained free of visible damage. Genetic differences in susceptibility to stressful agents or microhabitat differences may be important in explaining the differences in the development of stress symptoms within or between locations.

When the amount of damage in the August collection is used as an indicator of the onset of damage, the only measured variables significantly correlated with the damage are leaf Cl content, slope and width of the road shoulder (Table 3). Leaf chloride shows a positive correlation with damage, thus any factor which allows for a rapid uptake and accumulation of Cl will result in the early development of damage. The only factor correlated with the August leaf Cl was the width of the shoulder, the correlation was positive.

Slope was negatively correlated with the onset of damage. I believe this correlation is the result of the rapid movement of Cl through sites with steep slopes during spring runoff. Such an occurrence would in effect reduce the amount of Cl the trees would be exposed to.

Shoulder width was positively correlated with the damage in the August collection and to the Cl content of the vegetation. I believe that this is the result of two interacting factors: 1) a greater accumulation of Cl in locations with wide shoulders

due to road maintenance practices in which salt-laden snow and slush are plowed onto the road shoulders, and; 2) the negative correlation of shoulder width with slope which would tend to decrease the rate of water movement and inrease the Cl content.

The same relationships hold for correlations of the amount of damage in the September collections, an indicator of the severity of the damage.

Table 4 demonstrates that within locations damaged trees usually have a significantly larger Cl content than those trees not exhibiting stress symptoms. When the mean Cl content of all damaged trees is compared with the mean Cl content of undamaged trees, we find that the damaged trees contain significantly more Cl in their leaves. These data tend to confirm the results first demonstrated in Table 3 which was based on mean location Cl contents; that Cl content of leaf samples is directly related to the development of stress symptoms.

Tables 5, 6 and 7 illustrate the Cl relationships of vegetation within locations and demonstrates the reason behind the development of stress symptoms only in the 8 m sites. With the exception of the control location, Cl content of leaves from trees 8 m below the road is always significantly higher than that in the uphill or 24 m below the road sites. In the control location the Cl content of all sites in the June and August collections were statistically equivalent. In the September samples from the control location, the trees above the road actually contained more Cl than those below the road.

Tables 8, 9, and 10 document the rate of net Cl accumulation

in leaf samples. With very few exceptions a significant increase in Cl content from collection to collection was found. Shortle and Rich (1970) considered aspen to be a salt tolerant species as it did not exhibit stress symptoms when Cl was present in the leaf at 0.78 %. By the September collection the mean Cl content of trees in all of the 8 m sites, except the control, was greater than this value. Individual tree values reached a maximum of 2.9 % Cl while values as low as 0.6 % were found in trees exhibiting stress symptoms.

The same trend of Cl accumulation was also evident in the control location. The amount of Cl found in leaf samples from this location, was however, much lower than that found in the experimental locations.

Chloride content of the soils increased in the experimental sites between the June and August collections and then remained constant (Table 11). The increase in Cl content of the 8 and 24 m sites is thought to be the result of downhill migration of Cl due to the leaching of Cl from the soil by precipitation and runoff from the road. The increase in soil Cl in the uphill sites is not as easy to explain. Input as dust blown uphill from the road may account for some of this increase. Also, migration of Cl containing ground water (natural levels) from upslope areas may be a source. It is not known at this time whether evapotranspiration concentrates Cl in the soil solution.

The control location does not show a consistent pattern

of gain or loss of soil Cl. The uphill site remains constant while both the 8 and the 24 m sites show a peak Cl content in August. Reasons for the increase in soil chloride in the below the road sites are not clear. If dust were the cause of this input all three sites should have shown a similar increase.

Water contents of soil samples exhibit a more complex pattern than does Cl content (Table 11). Uphill sites in the experimental locations show a significant decrease in water content only in the September samples while the 24 m sites show a more gradual decrease throughout the year. Eight meter sites maintained a constant water content during these studies. The control location exhibits a more consistent pattern than was found in the experimental locations. All sites in this location show a maximum water content in August during the period of summer rains with both the June and September samples containing a significantly lower water content.

As chloride is an anion and as most soils have an extremelly low anion-exchange capacity, essentially all of the Cl present in the soil is found in the soil water (Bukman and Brady, 1969; Thomas and Swoboda, 1970). Chloride concentration is probably the most important variable in determining the rate of Cl uptake by vegetation for the simple reason that roots are more likely to come in contact with the ion in a concentrated solution than in a dilute solution. Chloride concentration is obviously a function of two variables, the amount of Cl present in the soil and the amount of water present. I have chosen to express the concentration as mg Cl/ g HOH.

Comparisons of Cl concentration in the 8 and the 24 m experimental sites shows a consistent pattern of increasing concentration from collection to collection. Maximum values occur in the September samples for all of the experimental sites. The increase in Cl concentration must be caused by the increased Cl content in the 8 m sites as the water content remained constant. In both the uphill and the 24 m sites the increase in concentration is caused both by an increase in Cl content and by the depletion of soil water. The control location shows basically the same pattern as that found in the experimental locations. Maximum concentrations were found in September, however, the differences found in the June and August samples were not significant.

Table 12 illustrates the relationships of these variables between sites. Chloride content is actually lower in the 8 m sites than in the other two sites in the June samples (probably as the result of leaching during spring snow melt), but because of the lower water content in the 8 m sites, the Cl concentrations are statistically equal. By the August collection sufficient Cl has entered the 8 m sites that all sites contained the same amount of Cl. In this collection the significantly lowered soil water content in the 8 m sites resulted in significantly higher Cl concentrations in these sites than in the others. In the September samples the interaction of a higher Cl content and a lowered soil water content again resulted in a signicantly higher Cl concentration in the 8 m sites than in either the

uphill or the 24 m sites. In the control location the only significant differences of Cl concentration which were found were in the August collections at which time the 8 and 24 m contained a significantly greater concentration than the uphill site. This difference was due to the higher Cl content of these sites at the time of collection.

Winter road maintenance practices include the application of road salt as a sand/salt mixture. Sufficient sand has been added that the sand which does enter the 8 m sites has resulted in a significant change in soil texture (Figure 1). This increase in sand is marked by the significant decrease in the percentage of both silt and clay. As the finer soil particles are most active in maintaining soil water (Buckman and Brady, 1969), even with an equal input of precipitation, the 8 m sites will be drier as they are unable to hold water. Winter snow is plowed from the road into the below the road sites, therefore these sites may actually receive more water than the above the road sites. As we have seen, however, the 8 m sites are consistently drier than the other sites and Table 3 demonstrates that one of the major reasons is the amount of sand present.

DISCUSSION

Numerous authors have investigated the role of road salt in the appearance of stress symptoms in roadside vegetation (Button and Peaslee, 1967; Hall et al., 1972; Hofstra and Hall, 1971; Holmes, 1961; Holmes and Baker, 1966; Lacasse and Rich,

1964; Menlove, 1973). Most of these authors did not sample extensively enough to produce statistically meaningful results or did not analyze their data at all. Many of these papers and innumerable others collected samples only after stress symptoms had developed and then collected leaf samples only. Gauch (1972) reports that stress symptoms often develop only after irreversible damage has already taken place. With the exception of Menlove (1973) essentially all of the work on stresses associated with road salting has been done in the northeastern United States and the southeastern portion of Canada. Our study was designed to collect enough samples frequently enough to produce statistically meaningful data which could explain both temporal and spatial variation. We were only partially successful. We did not measure several variables which may have been important, did not measure others often enough or completely enough, and, we are still analysing the data we have! The data we do have seems to point toward the over-riding importance of water in the development and extent of damage found.

Damage within roadside aspen trees did not become apparent until after the road was hard surfaced in 1971 although the road has been salted since 1948 (Piatt and Krause, 1974). The paved road is generally banked toward the uphill side of the road, I believe that because of this bank downhill movement of water is inhibited. Such an occurence would allow the Cl concentration to reach a high enough level that as it accumulates in the leaves it becomes directly toxic or through its osmotic role in the soil when combined with the approximately 50 % soil

water decrease damages the vegetation. While data is lacking, to date, to document this hypotheis several items point toward this conclusion.

Eubanks (1970) has shown that production of aspen plants decreases when they are subjected to an osmotic moisture stress. If we take the highest Cl concentration found in this investigation (3.2 mg Cl / g HOH) then at 20° C this concentration would result in a decrease in the soil water potential of approximately -1.9 atm. As aspen is unable to avoid drought-stress by closure of its stomates (Tobiessen and Kana, 1974) I feel that the damage found is at least partially due to the reduced water potential. We have seen that this reduction is caused by both the decrease in soil matrix potential and in the osmotic potential ultimately resulting in an internal moisture stress in the trees.

To my knowledge the only mechanism proposed to date to explain the occurence of stress symptoms in vegetation with high levels of Cl is that of Bingham et al. (1968). Their hypothesis, in essence, is that high levels of Cl cause a physiological (osmotic) moisture stress within the leaves. Taking the highest Cl content we found in leaf samples (2.9 %) and assuming that the dry weight of the samples is 20 % of the fresh weight, then at 20° C the osmotic pressure exerted by Cl alone is approximately -4.9 atm. This value is an order of magnitude lower (more negative) than that which would be found in the control locations. The significance of this difference in internal water status is difficult to assess, however the stress symptoms I found to be correlated with high Cl content

are virtually identical to those of aspen trees growing under a moisture stress in the absence of high leaf Cl contents (J.R. Piatt, personal communication). Other authors have noted the similarity of stress symptoms associated with Cl status with those exhibited under a moisture stress (Bernstein and Hayward, 1958; Bernstein, 1961).

O'Leary (1969) has published data which may have a bearing on the problem. One current hypothesis holds that plants can "overcome" a decrease in the soil water potential by proportionately decreasing the water potential in its own leaves by increasing the solute concentration (decreasing the osmotic potential). By so doing the plant would maintain the gradient of water potential in a favorable direction and thus be able to absorb water from the soil even at low soil water potentials. O'Learys data however showed that in a non-halophytic species (Phaseolis vulgaris L.) that increasing the salinity of the growth solution decreased the permiability of the roots in respect to water movement into the roots.

Finally, those road characteristics found to be associated with the development and severity of damage can best (and most easily) be explained by their actions on water flow or water holding capacity. In this regard the bank of the road may play a major role in the water relations of the 8 m sites. If the road is banked toward the downhill side, water flow from the road itself and from the uphill sites should not be greatly impeded. If, on the other hand, the road is banked toward the uphill side, any water falling on it would be forced to run

along the uphill road margin until it reached a culvert and would then be discharged into natural drainage areas.

Several hypothesis have been presented which can not be documented at this time. A complete understanding of the situation will be dependent upon a more complete data analysis and further measurements which were not taken in these studies. Upon completion of a more thorough data analysis the preparation of several manuscripts are planned which will be submitted to the Forest Service for approval.

RECOMMENDATIONS

Tentative recommendations are presented, however until the situation is more completely understood management alternatives are difficult to formulate.

The most logical alternative would be the complete stoppage of the application of the sand/salt mixture. Plowing the road is always sufficient to allow access to the Santa Fe Ski Basin if vehicles have good tires. The application of the sand/salt mixture at the present rate is not sufficient to prevent the formation of ice on the road in areas shaded during the afternoon. Select cutting of trees (of all species) which shade the road should result in more complete removal of ice without the necessity of salting.

Even if the application of this mixture is halted, some form of soil amendment should be applied to soils below the roadcut to increase the water holding capacity of the soils. Springfield (1972) has shown that a variety of mulches are effective in conserving soil moisture in the southwest. If these mulches were used in conjunction with plantings of salt tolerant grasses and forbs (Cordukes and Parups, 1971; Cordukes and MacLean, 1973; Hanes et al., 1970) natural increases in soil organic matter would eventually increase the water holding capacity of the disturbed sites. Plummer's (1970) work and species list of plants adapted to this forest type should provide clues to species of importance in this regard.

If road salt application continues I suggest that instead of the current practice of plowing snow into the downhill sites that the snow be plowed to the uphill side of the road. This

should prevent further increases in the sand content below the road and decrease the Cl input as well. Mulching and planting steps recommended above should be carried out.

Further disturbance to the below the road sites should be avoided. Further increases in sand content will surely result in a greater decrease in the water holding capacity of the soils and thus result in an increase in the soil Cl concentration. Such an increase will result in yet greater amounts of vegetation damage. Any method of increasing the input of water to these sites and of increasing the water holding capacity of the soils should receive serious consideration.

Literature Cited

Bernstein, L. 1961. Osmotic adjustment of plants to saline media. I. steady state. Amer. J. Bot. 48:909-918

Bernstein, L. and H.E. 1958. Physiology of salt tolerance. Ann. Rev. Plant Physiol. 9:25-46

Bingham, F.T., L.B. Fenn and J.J. Oertli. 1968. A sandculture study of chloride toxicity to mature avocado trees. Soil Sci. Soc. Amer. Proc. 34:249-252

Buckman, H.O. and N.C. Brady. 1969. The nature and property of soils. 7 th ed. The MacMillan Company 633 p.

Button, E.F. and D.E. Peaslee. 1967. The effects of road salt upon sugar maples in Connecticut. Highway Res. Record 161:121-131

Cantliffe, D.J., G.E. MacDonald and N.H. Peck. 1970. The potentiometric determination of nitrate and chloride in plant tissue. New York Food and Life Sci. Bull. #3

Cordukes, W.E. and E.V. Parups. 1971. Chloride uptake by various turfgrass species cultivars. Can. J. Plant Sci. 51:485-490

Cordukes, W.E. and A.J. MacLean. 1973. Tolerance of some turfgrass species to different concentrations of salt in soils. Can. J. Plant Sci. 53:69-73

Davies, R.G. 1971. Computer programming in quantitative biology. Academic Press. 492 p.

Eubanks, J.O. 1970. Effect of light intensity and osmotic stress on the water relations of *Populus tremuloides*. Forest Science 17:79-82

Gauch, H.G. 1972. Inorganic plant nutrition. Dowden, Hutchinson and Ross, Inc. 488 p.

Hall, R., G. Hofstra and G.P. Lumis. 1972. Effect of deicing salt on eastern white pine: foliar injury, growth supression and seasonal changes in foliar concentrations of sodium and chloride. Can. J. For. Res. 2:244-249

Hanes, R.E., L.W Zelazny and R.E. Blaser. 1970. Salt tolerance of trees and shrubs to de-icing salt. Highway Res. Rec. #355 pp 16-18

Herrington, R.B. 1967. Skiing trends and opportunities in the western states. USDA Forest Service Forest Service Res. Pap. INT-34

Hofstra, G. and R. Hall. 1971. Injury on roadside trees: leaf injury on pine and white cedar in relation to foliar levels of sodium and chloride. Can. J. Bot. 49:613-622

Holmes, F. 1961. Salt injury to trees. Phytopathology 51:712-717

Holmes, F. and J.H. Baker. 1966. Salt injury to trees: II. sodium and chloride in roadside sugar maples in Massachusetts. Phytopathology 56:633-636

Lacasse, N.L. and A.E. Rich. 1964. Maple decline in New Hampshire. Phytopathology 54:1071-1075

Lloyd, W.J. and P.E. Lemmon. 1969. Rectifying azimuth (of aspect) in studies of soil-site index relationships. pp. 435-448 In Youngberg, C.T. and C.B. Davey (eds.) Tree growth and forest soils. Oregon State Univ. Press, Corvalis. 527 p.

Lull, H.W. and K.G. Reinhart. 1955. Soil-moisture measurements. USDA Forest Service Southern Forest Expt. Sta. Occ. Pap. 140

Menlove, H.O. 1973. NaCl contamination in pine trees determined by neutron activation techniques. Water, Air and Soil Pollution 2:119-123

O'Leary, J.W. 1969. The effect of salinity on permeability of roots to water. Israel J. Bot. 18:1-9

Piatt, J.R. and P.D. Krause. 1974. Road and site characteristics that influence road salt distribution and damage to roadside aspen trees. Water, Air and Soil Pollution 3:301-304

Plummer, A.P. 1970. Plants for revegetation of roadcuts and other disturbed or eroded areas. USDA Forest Service, Intermountain Region Range Improvement Notes 15:1-8

Shortle, W.C. and A.E. Rich. 1970. Relative sodium chloride tolerance of common roadside trees in southeastern New Hampshire. Plant Disease Reptr. 54:360-362

Sonneveld, C. and J. Van Den Ende. 1971. Soil analysis by means of a 1:2 volume extract. Plant and Soil 35:505-516

Springfield, H.W. 1972. Using mulches to establish woody chenopods. pp. 382-391 <u>In</u> Wildland shrubs - their biology and utilization. USDA Forest Service Gen. Tech. Rep. INT-1

Thomas, G.W. and A.R. Swoboda. 1970. Anion exclusion effects on chloride movement in soils. Soil Sci. 110:163-16

Tobiessen, P. and T.M. Kana. 1974. Drought-stress avoidance in three pioneer tree species. Ecology 55:667-670

Table 1

CHARACTERISTICS OF STUDY LOCATIONS ESTABLISHED JUNE 1973

Location #	Shoulder Width (m) Mean	Max.	Min.	Distance to trees in 8 m sites Mean	Max.	Min.	Aspect	Elevation (m)	Mean Slope (°)
1	0.91	1.22	0.61	9.14	11.58	6.22	N	2957	33
2	1.03	3.35	0.00	11.39	16.15	8.38	NE	2996	30
3	0.00	0.00	0.00	8.24	10.55	5.94	SW	3033	34
4	3.76	3.96	3.05	8.87	10.55	7.86	W	3033	25
5	4.78	5.27	4.45	8.70	10.55	6.71	WNW	3002	14
6	1.00	1.10	0.82	9.50	13.11	5.88	WSW	2984	37
7	0.19	0.49	0.00	7.31	9.02	5.21	W	2987	34
8	7.51	8.69	6.52	9.60	12.04	8.08	W	3014	8
9	1.07	2.32	0.00	8.76	12.50	5.40	WSW	3018	24
10	0.43	1.34	0.00	8.83	11.16	6.28	W	3078	29
11	2.20	2.44	1.77	9.29	11.16	7.71	WSW	3130	30
12	2.90	4.18	2.26	9.69	12.07	7.83	W	3170	38
13	*	*	*	8.41	9.62	7.87	S	3109	30

* Location 13 is along an unpaved special use road.

Table 2

PERCENTAGE OF TREES SHOWING DAMAGE IN 8.0 m STUDY SITES

Location	June	August	September
1	0	0	30
2	0	10	50
3	0	0	0
4	0	0	50
5	0	10	30
6	0	0	10
7	0	0	30
8	0	20	60
9	0	0	0
10	0	0	10
11	0	0	30
12	0	0	20
13 [1]	0	0	0

1. Location 13 is along an unpaved, unsalted special use road.

Table 3

CORRELATIONS OF DAMAGE MEASUREMENTS WITH MEASURED PARAMETERS

IN 8.0 m SITES

Row	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
1	1.000																					
2	#	1.000																				
3	0.599*	0.874**	1.000																			
4	0.366	0.865**	#	1.000																		
5	-0.050	0.005	-0.159	0.122	1.000																	
6	0.006	0.198	0.086	0.303	0.520	1.000																
7	-0.135	-0.063	-0.142	0.097	0.816**	0.029	1.000															
8	0.144	0.106	-0.060	0.180	#	0.595*	0.734**	1.000														
9	-0.192	-0.130	-0.040	0.114	0.510	#	0.172	0.475	1.000													
10	0.309	0.175	-0.103	0.015	0.527	0.179	#	0.688*	-0.239	1.000												
11	0.307	0.251	0.450	0.199	-0.619*	-0.177	-0.655*	-0.634*	-0.080	-0.581*	1.000											
12	-0.186	-0.097	0.036	-0.180	-0.780*	-0.389	-0.706*	-0.906**	-0.229	-0.643*	0.611*	1.000										
13	0.240	0.099	-0.040	0.162	0.809**	0.356	0.736**	0.915**	0.248	0.651*	-0.586*	-0.990**	1.000									
14	-0.066	0.062	-0.020	0.260	0.488	0.423	0.429	0.670*	0.088	0.472	-0.610*	-0.826**	0.740*	1.000								
15	-0.020	-0.081	-0.197	0.033	0.951**	0.539	0.771**	0.941**	0.589*	0.482	-0.619*	-0.828**	0.848**	0.564	1.000							
16	-0.129	0.087	-0.081	0.230	0.812**	0.476	0.782**	0.855**	0.425	0.611*	-0.677*	-0.684*	0.687*	0.517	0.771*	1.000						
17	0.233	0.402	0.338	0.406	-0.006	0.526	-0.203	0.266	-0.082	0.342	-0.184	-0.355	0.256	0.682*	0.041	0.120	1.000					
18	-0.799**	-0.598*	-0.391	-0.210	-0.020	0.291	-0.170	-0.147	0.275	-0.355	-0.076	0.184	-0.261	0.144	-0.072	0.045	0.087	1.000				
19	0.760**	0.652*	0.595*	0.435	-0.063	-0.201	0.005	-0.003	-0.152	0.024	0.492	-0.060	0.127	-0.239	-0.040	-0.183	-0.160	-0.811**	1.000			
20	0.409	0.400	0.506	0.284	-0.490	0.046	-0.634*	-0.359	-0.335	-0.218	0.461	0.179	-0.247	0.131	-0.437	-0.612*	0.600*	-0.040	0.201	1.000		
21	0.433	0.441	0.370	0.287	0.287	0.025	0.019	0.239	0.025	0.176	0.361	-0.314	0.327	0.161	0.218	-0.081	0.240	-0.190	0.476	0.420	1.000	
22	-0.228	-0.156	0.143	-0.433	-0.433	0.274	-0.349	-0.500	0.274	-0.790**	0.583*	0.596*	-0.599*	-0.471	-0.322	-0.388	-0.413	0.209	0.094	0.104	-0.222	1.000

1. Percentage Damage - August Collection
2. Percentage Damage - September Collection
3. Leaf Chloride - August Collection
4. Leaf Chloride - September Collection
5. August Soil Cl - meq Cl/100 g soil
6. August Soil Cl - mg Cl/g HOH
7. August Soil HOH - g HOH/g soil
8. September Soil Cl - meq Cl/100 g soil
9. September Soil Cl - mg Cl/g HOH
10. September Soil HOH - g HOH/g soil
11. Gravel Content - %
12. Sand Content - %
13. Silt Content - %
14. Clay Content - %
15. Organic Matter - %
16. Litter Depth - m
17. Aspect - 1.0+ cosine Asimuth (Lloyd and Lemmon)
18. Slope - degrees
19. Shoulder Width
20. Distance to Trees in 8.0 m sites- m
21. DBH - cm
22. Elevation - m

* Significant at the 0.05 level.

** Significant at the 0.01 level.

Product-moment correlation coefficients are inappropriate for these data (Davies, 1971)

Table 4

COMPARISON OF CHLORIDE CONTENT IN DAMAGED AND UNDAMAGED LEAVES

SEPTEMBER COLLECTION 8.0 m SITES

(PERCENTAGE * OF OVEN DRY WEIGHT)

Location	Damaged	Undamaged	LSR
1	0.811 a **	1.278 a	0.899
2	1.712 a	1.732 a	0.301
4	2.196 a	1.756 b	0.208
5	2.107 a	1.008 b	0.468
6	1.420 a	0.714 a	0.852
7	1.683 a	1.247 b	0.102
8	1.960 a	0.700 b	0.497
10	1.720 a	0.886 b	0.473
11	1.343 a	0.956 b	0.201
12	1.575 a	1.286 a	0.930
Mean	1.766 a ***	1.136 b	0.215

* All data was transformed to its arcsin prior to analysis.

** Values within a row not followed by the same letter are significantly different at the 0.05 level. Values are the mean of all damaged or undamaged leaves within the site.

*** Means not followed by the same letter are significantly different at the 0.05 level. Values are the mean chloride content of all damaged and undamaged leaf samples in all 8.0 m sites.

Table 5

COMPARISONS OF CHLORIDE CONTENT IN JUNE VEGETATION SAMPLES

(Percentage* of Oven Dry Weight)

Location	Uphill	8.0 m	24.0 m
1	0.106 b**	0.194 a	0.088 b
2	0.096 b	0.425 a	0.187 b
3	0.080 b	0.165 a	0.066 b
4	0.097 b	0.364 a	0.162 b
5	0.102 b	0.200 a	0.078 c
6	0.046 b	0.096 a	0.068 b
7	0.079 b	0.190 a	0.073 b
8	0.071 b	0.179 a	0.072 b
9	0.076 b	0.139 a	0.074 b
10	0.110 b	0.219 a	0.101 b
11	0.068 b	0.176 a	0.084 b
12	0.072 b	0.250 a	0.096 b
13[1]	0.057 a	0.053 a	0.048 a
Mean	0.084 b ***	0.216 a	0.094 b

* Data was transformed to its arcsin prior to analysis.

** Values within a row not followed by the same letter are significantly different at the 0.05 level. Values are the mean of ten samples.

*** Means not followed by the same letter are significantly different at the 0.05 level. Values are the mean of data from locations 1-12.

1 Location 13 is along an unsalted unmaintained access road.

Table 6

COMPARISONS OF CHLORIDE CONTENT IN AUGUST VEGETATION SAMPLES

(PERCENTAGE * OF OVEN DRY WEIGHT)

Location	Uphill	8.0 m	24.0 m
1	0.204 b**	0.545 a	0.205 b
2	0.235 b	1.208 a	0.475 b
3	0.202 b	0.547 a	0.213 b
4	0.217 b	1.143 a	0.300 b
5	0.169 b	0.810 a	0.112 b
6	0.137 b	0.405 a	0.218 b
7	0.173 b	0.652 a	0.170 b
8	0.161 b	1.112 a	0.137 b
9	0.164 b	0.314 a	0.184 b
10	0.239 b	0.622 a	0.230 b
11	0.188 b	0.740 a	0.245 b
12	0.163 b	0.879 a	0.194 b
13 [1]	0.101 a	0.088 a	0.078 a
Mean	0.188 b***	0.748 a	0.224 b

* Data was transformed to arcsin prior to analysis.

** Values within a row not followed by the same letter are significantly different at the 0.05 level. Values are the mean of ten samples.

*** Means not followed by the same letter are significantly different at the 0.05 level. Values are the mean of data from locations 1-12.

1 Location 13 is along an unsalted unmaintained access road.

Table 7

COMPARISONS OF CHLORIDE CONTENT IN SEPTEMBER VEGETATION SAMPLES

(PERCENTAGE * OF OVEN DRY WEIGHT)

Location	Uphill	8.0 m	24.0 m
1	0.290 b **	1.248 a	0.280 b
2	0.293 c	1.722 a	0.701 b
3	0.346 b	0.873 a	0.374 b
4	0.360 b	1.976 a	0.478 b
5	0.269 b	1.338 a	0.194 b
6	0.197 b	0.785 a	0.344 b
7	0.249 b	1.378 a	0.284 b
8	0.224 b	1.456 a	0.212 b
9	0.234 b	0.452 a	0.244 b
10	0.356 b	0.969 a	0.367 b
11	0.310 b	1.072 a	0.382 b
12	0.258 b	1.344 a	0.343 b
13[1]	0.174 a	0.141 b	0.136 b
Mean	0.282 b ***	1.218 a	0.350 b

* Data was transformed to arcsin prior to analysis.

** Values within a row not followed by the same letter are significantly different at the 0.05 level. Values are the mean of ten samples.

*** Means not followed by the same letter are significantly different at the 0.05 level. Values are the mean of data from locations 1-12.

1 Location 13 is along an unsalted unmaintained access road.

Table 8

COMPARISON OF CHLORIDE CONTENT IN UPHILL VEGETATION BY COLLECTION PERIOD

(PERCENTAGE * OF OVEN DRY WEIGHT)

Location	June	August	September
1	0.106 c **	0.204 b	0.290 a
2	0.096 c	0.235 b	0.293 a
3	0.080 c	0.202 b	0.346 a
4	0.097 c	0.217 b	0.360 a
5	0.102 c	0.169 b	0.269 a
6	0.046 c	0.137 b	0.197 a
7	0.079 c	0.173 b	0.249 a
8	0.071 c	0.161 b	0.224 a
9	0.076 c	0.164 b	0.234 a
10	0.110 c	0.239 b	0.356 a
11	0.068 c	0.188 b	0.310 a
12	0.072 c	0.163 b	0.258 a
13 [1]	0.057 c	0.101 b	0.174 a
Mean	0.084 c ***	0.188 b	0.282 a

* Data was transformed to its arcsin prior to analysis.

** Values within a row not followed by the same letter are significantly different at the 0.05 level. Values are the mean of ten samples.

*** Means not followed by the same letter are significantly different at the 0.05 level. Values are the mean of data from locations 1-12.

1 Location 13 is along an unsalted unmaintained access road.

Table 9

COMPARISON OF CHLORIDE CONTENT IN 8.0 m VEGETATION BY COLLECTION PERIOD

(PERCENTAGE * OF OVEN DRY WEIGHT)

Location	June	August	September
1	0.194 c **	0.545 b	1.248 a
2	0.425 c	1.208 b	1.722 a
3	0.165 c	0.547 b	0.873 a
4	0.365 c	1.143 b	1.976 a
5	0.200 c	0.810 b	1.338 a
6	0.096 c	0.405 b	0.785 a
7	0.190 c	0.652 b	1.378 a
8	0.179 b	1.112 a	1.456 a
9	0.139 b	0.314 a	0.452 a
10	0.219 c	0.622 b	0.969 a
11	0.176 c	0.740 b	1.072 a
12	0.250 c	0.879 b	1.344 a
13 [1]	0.053 c	0.088 b	0.141 a
Mean	0.216 c ***	0.748 b	1.218 a

* Data was transformed to its arcsin prior to analysis.

** Values within a row not followed by the same letter are significantly different at the 0.05 level. Values are the mean of ten samples.

*** Means not followed by the same letter are significantly different at the 0.05 level. Values are the mean of data from locations 1-12.

1 Location 13 is along an unsalted unmaintained access road.

Table 10

COMPARISON OF CHLORIDE CONTENT IN 24.0 m VEGETATION BY

COLLECTION PERIOD

(PERCENTAGE * OF OVEN DRY WEIGHT)

Location	June	August	September
1	0.088 c **	0.205 b	0.280 a
2	0.167 c	0.475 b	0.701 a
3	0.066 c	0.213 b	0.374 a
4	0.162 c	0.300 b	0.478 a
5	0.078 c	0.112 b	0.194 a
6	0.068 c	0.218 b	0.344 a
7	0.073 c	0.170 b	0.284 a
8	0.072 c	0.137 b	0.212 a
9	0.074 c	0.184 b	0.244 a
10	0.101 c	0.230 b	0.367 a
11	0.084 c	0.245 b	0.382 a
12	0.096 c	0.194 b	0.343 a
13 [1]	0.048 c	0.078 b	0.136 a
Mean	0.094 c ***	0.224 b	0.350 a

* Data was transformed to its arcsin prior to analysis.

** Values within a row not followed by the same letter are significantly different at the 0.05 level. Values are the mean of ten samples.

*** Means not followed by the same letter are significantly different at the 0.05 level. Values are the mean of data from locations 1-12.

1 Location 13 is along an unsalted unmaintained access road.

TABLE 11

SOIL DATA

COMPARISONS OF COLLECTION DATES

Sample	Data	June	August	September
		Chloride Content (meq Cl/100 g soil)		
Above Road Cut	Location 13[1]	0.029 a*	0.047 a	0.065 a
	Locations 1-12	0.060 b**	0.119 a	0.117 a
8.0 m Below Pavement	Location 13	0.044 b*	0.112 a	0.068 b
	Locations 1-12	0.045 b**	0.124 a	0.152 a
24.0 m Below Pavement	Location 13	0.040 b*	0.121 a	0.070 ab
	Locations 1-12	0.060 b**	0.122 a	0.128 a
		WATER CONTENT (g HOH/g soil)		
Above Road Cut	Location 13[1]	0.078 b*	0.164 a	0.085 b
	Locations 1-12	0.138 a**	0.125 a	0.099 b
8.0 m Below Pavement	Location 13	0.155 b*	0.207 a	0.084 b
	Locations 1-12	0.086 a**	0.081 a	0.076 a
24.0 m Below Pavement	Location 13	0.121 b*	0.212 a	0.114 b
	Locations 1-12	0.137 a**	0.120 ab	0.108 b
		Chloride Concentration (mg Cl/g HOH)		
Above Road Cut	Location 13[1]	0.142 b*	0.103 b	0.314 a
	Locations 1-12	0.167 b**	0.396 a	0.461 a
8.0 m Below Pavement	Location 13	0.137 b*	0.191 b	0.302 a
	Locations 1-12	0.193 c**	0.548 b	0.855 a
24.0 m Below Pavement	Location 13	0.117 b*	0.194 ab	0.210 a
	Locations 1-12	0.173 c**	0.390 b	0.470 a

* Values within a row not followed by the same letter are significantly different at the 0.05 level. Values are the mean of five samples.

** Values within a row not followed by the same letter are significantly different at the 0.05 level. Values are the mean of sixty samples (five per location).

1 Location 13 is along an unsalted unmaintained access road.

TABLE 12

SOIL DATA

COMPARISONS OF SAMPLING SITES WITHIN A LOCATION

Variable	Data	Above Road cut	8.0 m Below pavement	24.0 m Below pavement
		June 1973		
Chloride Content (meq Cl/100 g soil)	Location 13[1]	0.029 a*	0.044 a	0.040 a
	Locations 1-12	0.060 a**	0.045 b	0.060 a
Water Content (g HOH/g soil)	Location 13	0.078 b*	0.115 ab	0.121 a
	Locations 1-12	0.138 a**	0.086 b	0.137 a
Chloride Concentration (mg Cl/g HOH)	Location 13	0.142 a*	0.137 a	0.117 a
	Locations 1-12	0.170 a	0.193 a	0.173 a
		August 1973		
Chloride Content (meq Cl/100 g soil)	Location 13[1]	0.047 b*	0.112 a	0.121 a
	Locations 1-12	0.119 a**	0.124 a	0.123 a
Water Content (g HOH/g soil)	Location 13	0.164 a*	0.207 a	0.212 a
	Locations 1-12	0.125 a**	0.081 b	0.120 a
Chloride Concentration (mg Cl/g HOH)	Location 13[1]	0.103 a*	0.191 a	0.194 a
	Locations 1-12	0.396 b**	0.548 a	0.390 b
		September 1973		
Chloride Content (meq Cl/100 g soil)	Location 13[1]	0.065 a*	0.068 a	0.070 a
	Locations 1-12	0.117 b**	0.152 a	0.128 ab
Water Content (g HOH/g soil)	Location 13	0.085 a*	0.084 a	0.114 a
	Locations 1-12	0.099 a**	0.076 b	0.108 a
Chloride Concentration (mg Cl/g HOH)	Location 13	0.314 a*	0.302 a	0.314 a
	Locations 1-12	0.500 b**	0.855 a	0.468 b

* Values within a row not followed by the same letter are significantly different at the 0.05 level. Values are the mean of five samples.

** Values within a row not followed by the same letter are significantly different at the 0.05 level. Values are the mean of sixty samples (five per location).

1 Location 13 is along an unsalted unmaintained access road.

FIG. 1 SOIL TEXTURE IN EXPERIMENTAL LOCATIONS

" UP " refers to uphill sites

" 8 m " refers to sites 8 m below road pavement

" 24 m " refers to sites 24 m below road pavement